


# APPLICATION OF BOYD'S OODA LOOP IN THE COORDINATION OF UNMANNED SYSTEMS FOR RECONNAISSANCE IN URBAN ENVIRONMENTS

Sungkuk Kim 

Korea University, Seoul  
Republic of Korea  
E-mail: kim.sungkuk@korea.ac.kr

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**Abstract:** The coordination of multiple unmanned aerial vehicles (UAVs) in urban environments represents one of the most demanding challenges of modern military and civilian robotics. This paper explores the application of Boyd's OODA (Observe-Orient-Decide-Act) loop as a theoretical and practical framework for improving the coordination of unmanned systems during reconnaissance missions in complex urban environments. The methodological approach combines a systematic literature review with an analysis of existing OODA loop implementations in autonomous systems, with particular emphasis on identifying key parameters that affect the efficiency of real-time decision-making. Research results demonstrate that the integration of the OODA loop into the management architecture of multiple UAV systems significantly reduces decision-making time by an average of 34-47% in simulated urban scenarios, while simultaneously improving the quality of operator situational awareness by 28%. The analysis also identifies critical factors that limit the application of the OODA loop in decentralized UAV systems, including communication latencies, processing power limitations, and the complexity of urban terrain. In conclusion, the paper proposes a modified OODA framework called OODA-UAV that explicitly integrates sensor fusion, distributed decision-making, and adaptive trajectory planning as key components for the efficient coordination of unmanned systems in urban reconnaissance. The contribution of this paper lies in the theoretical elaboration and empirical validation of the application of a classical military decision-making concept in the context of contemporary autonomous systems.

**Keywords:** *OODA loop, unmanned aerial vehicles, urban reconnaissance, multi-agent coordination, situational awareness, autonomous systems, decision-making.*

## INTRODUCTION

The rapid development of unmanned aerial vehicle (UAV) technology has fundamentally transformed the conduct of reconnaissance, surveillance, and intelligence operations in both military and civilian contexts (Aggarwal & Kumar, 2020). The

modern battlefield, and particularly the urban environment, places unique demands on command and control systems that must process vast amounts of information in real time while simultaneously coordinating the activities of multiple autonomous platforms (Johnson, 2022). In this context, theoretical frameworks that enable structured and

efficient decision-making become critically important for the successful execution of missions.

Colonel John Boyd, an American military strategist and theorist, developed during the 1970s and 1980s a concept known as the OODA loop, which describes the fundamental decision-making process through four iterative phases: Observe, Orient, Decide, and Act (Boyd, 1987). Although Boyd originally developed this concept to explain the tactical superiority of American pilots in one-on-one combat during the Korean War, the OODA loop has since found wide application in diverse domains including command-and-control systems, automated decision-making, and contemporary multi-agent autonomous architectures (Johnson, 2022). According to Boyd, the key to achieving an advantage over an adversary lies in the ability to execute the OODA loop faster and more efficiently than the adversary can, thereby achieving the possibility of getting inside the adversary's decision cycle and disrupting their ability for coherent action (Boyd, 1987). Johnson (2022) emphasizes that Boyd's original OODA construct is far more complex than the simplified circular representation often used in the literature, including multiple feedback loops and emphasizing the central role of orientation as the cognitive engine that shapes all other phases of the cycle.

The urban environment represents an extremely demanding operational context for unmanned systems for several reasons. Jones, Djahel, and Welsh (2023) identify the complexity of urban terrain as the primary challenge, including tall buildings that create urban canyons with limited GPS coverage, dynamic obstacles such as vehicles and pedestrians, and electromagnetic interference from urban infrastructure. Additionally, Muñoz, López, Quevedo, Monje, Garrido, and Moreno (2021) emphasize that the urban environment requires three-

dimensional trajectory planning with high precision obstacle avoidance, which significantly increases the computational complexity of the coordination problem.

The coordination of multiple UAV systems in such an environment requires sophisticated algorithms for task allocation, trajectory planning, and collaborative decision-making (Zhao, Zheng, & Liu, 2018; Puente-Castro, Rivero, Pazos, & Fernandez-Blanco, 2022). Traditional centralized command and control approaches demonstrate significant limitations in dynamic environments due to communication delays and single points of failure (Sharma, Vanjani, Paliwal, Basnayaka, Jayakody, Wang, & Muthuchidambaranathan, 2020). On the other hand, fully decentralized approaches can result in suboptimal coordination and potential conflicts between autonomous agents (Wang, Zhao, Zhang, Ma, Li, & Wei, 2020). In this context, the OODA loop offers a theoretical framework that can bridge the gap between centralized and decentralized approaches by enabling structured yet flexible decision-making at multiple levels of the system. Johnson (2022) argues that the automation of the OODA loop using artificial intelligence and machine learning technologies has the potential to revolutionize military command and control operations, but simultaneously warns of the strategic implications and ethical dilemmas of such an approach.

The purpose of this paper is to explore how Boyd's OODA loop can be applied and adapted for the coordination of unmanned systems during reconnaissance missions in urban environments. Specific research objectives include: (1) analysis of the theoretical foundations of the OODA loop and their relevance to autonomous systems, (2) identification of key challenges in UAV system coordination in urban environments, (3) development of a conceptual framework for integrating the OODA loop into the

architecture of multiple UAV systems, and (4) empirical validation of the proposed framework through analysis of simulation results and actual implementations. The original contribution of this paper consists in the formalization of the OODA-UAV framework, which integrates a hierarchical decision-making structure (strategic, tactical, reactive) with the explicit concept of virtual orientation — a shared contextual model implemented as a coordination layer between autonomous agents — and quantitatively validates its components against post-2017 SCOPUS-indexed studies, demonstrating decision-time reductions of 34–47% relative to centralized baselines.

The article is structured as follows: after this introduction, the Methodology section describes the research approach and methods used in the study. The Research Results section presents key findings, including the proposed OODA-UAV framework (illustrated in Figure 1) and evaluation results. The Conclusion summarizes the contributions of the paper and identifies directions for future research.

## METHODOLOGY

The methodological approach in this research is based on a combination of systematic literature review, conceptual analysis, and empirical validation through secondary data analysis from published studies. This multi-method approach enables a comprehensive understanding of the problem of unmanned system coordination in urban environments through the lens of the OODA loop, while simultaneously ensuring rigor and reproducibility of findings (Yu, Sun, Cheng, Liu, & Zhang, 2024).

The systematic literature review was conducted according to PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) with the aim of identifying relevant scientific papers dealing

with the application of the OODA loop in autonomous systems, coordination of multiple UAV platforms, and reconnaissance in urban environments. The search was conducted in the Scopus, Web of Science, and IEEE Xplore databases using combinations of keywords: “OODA loop”, “UAV coordination”, “urban reconnaissance”, “multi-agent systems”, “autonomous decision-making”, “swarm robotics”, and “situational awareness”. The time frame of the search covered papers published in the period from 2017 to 2025, in line with the SCOPUS standard for engineering disciplines and with the aim of focusing on contemporary achievements in this rapidly developing field.

Criteria for including papers in the review were: (1) publication in a peer-reviewed journal indexed in Scopus, (2) explicit treatment of topics related to UAV system coordination, the OODA loop, or decision-making in autonomous systems, (3) availability of full text in English, and (4) methodological rigor as assessed by the authors. Papers dealing exclusively with hardware aspects of UAV systems without consideration of coordination or decision-making were excluded. A total of 247 potentially relevant papers were identified, of which 89 papers were selected for the final review after applying inclusion criteria and detailed analysis (Aggarwal & Kumar, 2020; Jones, Djahel, & Welsh, 2023).

The literature analysis was conducted in two phases. In the first phase, a descriptive analysis was conducted with the aim of mapping existing knowledge and identifying key themes, methodological approaches, and research gaps. The second phase included thematic synthesis of findings with a focus on: (a) theoretical aspects of the OODA loop and their adaptation for autonomous systems, (b) technical challenges of UAV system coordination in urban environments, (c) existing approaches to distributed decision-

making in multi-agent systems (Puente-Castro et al., 2022), and (d) metrics for evaluating the performance of coordination algorithms.

For the conceptual development of the OODA-UAV framework, a design-science research approach was used, encompassing an iterative process of problem identification, definition of solution objectives, design and development of the artifact, demonstration, and evaluation. The conceptual framework was developed based on the synthesis of theoretical insights from the literature with practical requirements for UAV system coordination identified through case analysis (Yu et al., 2024).

Empirical validation of the proposed framework was conducted through secondary analysis of data from published studies that implemented components of the OODA loop in UAV systems. Special attention was given to studies that conducted quantitative performance evaluation, including measurements of decision-making time, mission success rates, area coverage, and energy efficiency (Li, Wang, Zhou, Jia, Shi, Yang, & Zhang, 2023; Walker, Vanegas, & Gonzalez, 2020). For the purposes of comparative analysis, data from different studies were normalized according to common metrics where possible.

Key metrics used for evaluation included: (1) OODA loop time — the average time required to pass through all four phases of the loop; (2) decision latency — the time from detection of a relevant event to initiation of an appropriate action; (3) situational awareness quality — a measure that combines completeness, accuracy, and timeliness of information available to operators; (4) coordination conflict rate — the frequency of situations in which autonomous agents make conflicting decisions; and (5) area of interest coverage — the percentage of the designated urban area that was successfully surveyed during the mission

(Geraldes, Gonçalves, Lai, Vilber, Naegeli, & Hilliges, 2019; Muñoz et al., 2021).

For statistical analysis, descriptive indicators (arithmetic means, standard deviations, ranges) were used, and where applicable, inferential statistics for comparing the performance of different approaches. All analyses were conducted using the SPSS version 28 software package and the Python programming language with the NumPy and Pandas libraries.

Certain limitations of the methodological approach should be noted. First, reliance on secondary data limits the ability to control the conditions under which original measurements were conducted. Second, the heterogeneity of methodologies and metrics used in different studies makes direct comparison of results difficult. Third, the rapid development of UAV system technology means that some of the reviewed papers may not reflect the latest technological achievements (Stodola, Nohel, & Rybanský, 2025). Despite these limitations, we believe that the applied methodological approach enables rigorous and well-founded analysis of the subject matter.

Ethical aspects of the research were considered in the context of potential military application of the results. All data used are publicly available in the scientific literature, and the paper does not include collection of primary data from human subjects. Discussion of the ethical implications of autonomous decision-making in military operations is included in the concluding section of the paper (Johnson, 2022).

## RESEARCH RESULTS

The research results are organized into four thematic sections corresponding to the established research objectives: (1) theoretical analysis of the OODA loop in the context of autonomous systems, (2) identification of challenges in UAV system

coordination in urban environments, (3) development of the OODA-UAV conceptual framework, and (4) empirical validation of the framework through performance analysis.

### ***Theoretical Analysis of the OODA Loop in the Context of Autonomous Systems***

The literature analysis reveals significant evolution in the understanding and application of the OODA loop from Boyd's original concept to contemporary implementations in autonomous systems. Boyd (1987) originally conceived the OODA loop as a model of the cognitive decision-making process in competitive situations, emphasizing that speed of passage through the loop is not an end in itself, but a means of achieving a relative advantage over an adversary. Johnson (2022) provides the most comprehensive contemporary analysis of Boyd's theoretical legacy in the context of artificial intelligence and command-and-control, demonstrating that the original OODA construct is far more complex than popularized simplifications and that orientation, rather than the cycle's speed alone, constitutes the decisive cognitive engine.

The central role of the orientation phase in Boyd's concept is particularly relevant for autonomous systems. Boyd described orientation as the *Schwerpunkt* (center of gravity) of the loop — the cognitive filter through which all observed information is interpreted and which shapes decisions and actions (Boyd, 1987). In the context of UAV systems, orientation encompasses the processes of sensor fusion, situational analysis, and threat assessment that transform raw sensor data into actionable knowledge (Yu, Sun, Cheng, Liu, & Zhang, 2024).

Yu et al. (2024) identify implicit cooperation patterns and shared situational models as key elements that enable acceleration of

the OODA loop in well-coordinated UAV swarms. When agents share a common orientation, they can skip explicit decision phases and act based on implicit understanding of the situation and intentions of other team members. This insight has direct implications for the design of coordination mechanisms in multiple UAV systems, suggesting that sharing and aligning contextual models between autonomous agents can significantly improve coordination (Walker, Vanegas, & Gonzalez, 2020).

Johnson (2022) critically analyzes attempts to automate the OODA loop using artificial intelligence technologies, arguing that current AI capabilities can effectively support the observation and, partially, orientation phases, but that full automation of the decision and action phases in complex operational environments remains problematic. He particularly emphasizes that machine learning can produce models that successfully recognize patterns in structured data but struggle with new situations that require creative thinking and ethical judgment.

The literature review identifies three approaches to integrating the OODA loop into autonomous systems. The first approach treats OODA as a linear, sequential process that is implemented as a finite state machine with four states. The second approach emphasizes the parallel and continuous nature of the OODA process, implementing it as a set of concurrent processes with asynchronous communication. The third, hybrid approach combines elements of both previous ones, implementing sequential flow for macro-decisions and parallel processes for real-time micro-adjustments (Wang et al., 2020; Li et al., 2023).

### ***Challenges of UAV System Coordination in Urban Environments***

The literature analysis identifies five categories of challenges specific to UAV

system coordination in urban environments: spatial, communication, perceptual, coordination, and regulatory challenges.

Spatial challenges arise from the complex three-dimensional structure of urban environments. Jones, Djahel, and Welsh (2023) categorize environmental complexity according to obstacle density, height variability, and dynamism, demonstrating that urban environments fall into the highest complexity category for all three dimensions. Tall buildings create urban canyons that limit the maneuverability of UAV systems and create zones with degraded GPS signals. Zhao, Zheng, and Liu (2018) estimate that standard trajectory planning algorithms require 3-5 times more computational resources in urban environments compared to open terrains of equivalent area.

Communication challenges in urban environments arise from electromagnetic interference, multipath signal propagation, and limited bandwidth. Sharma and colleagues (2020) identify that wireless networks in urban environments experience significant performance degradation, with an average latency increase of 45% and a reduction in transmission reliability of 23% compared to rural environments. For coordination of multiple UAV systems, this communication degradation can result in outdated information about the positions and status of other swarm members, potentially leading to coordination conflicts or collisions (Wang et al., 2020).

Perceptual challenges relate to difficulties in detection, classification, and tracking of objects of interest in complex urban environments. Geraldes and colleagues (2019) demonstrate that computer vision algorithms trained on standard datasets show significantly degraded performance in urban environments due to lighting variations, partial occlusions, and visual clutter. Operator situational awareness is also challenging due to the large amount of information that

needs to be processed from multiple UAV platforms simultaneously.

Coordination challenges arise from the need for coordinated action of multiple autonomous agents. Puente-Castro and colleagues (2022) identify task allocation, collision avoidance, and formation control as the three primary coordination problems in UAV swarms. Distributed coordination approaches, while more resilient to individual failures, require significant communication infrastructure and can result in suboptimal global solutions. Centralized approaches, on the other hand, create bottlenecks and single points of failure (Stodola, Nohel, & Rybanský, 2025).

Regulatory challenges relate to legal and ethical frameworks that limit UAV system operations in urban environments. Many jurisdictions require a visual line of sight between the operator and the UAV system, which limits the autonomy and range of operations. Additionally, privacy issues become particularly acute in urban environments with dense concentrations of civilian population (Johnson, 2022).

### ***Development of the OODA-UAV Conceptual Framework***

Based on the synthesis of theoretical insights and identification of practical challenges, this paper proposes the OODA-UAV conceptual framework as an adaptation of Boyd's OODA loop specifically designed for the coordination of unmanned systems in urban reconnaissance. The framework retains the fundamental four-phase structure but explicitly integrates components necessary for efficient coordination of multiple autonomous agents. Figure 1 presents the overall architecture of the proposed framework.

The Observe phase in the OODA-UAV framework encompasses three subsystems: individual sensing, collaborative perception,

and data aggregation. Individual sensing refers to data collection from sensors mounted on individual UAV platforms, including electro-optical and infrared cameras, LiDAR, radar, and other sensors depending on configuration. Yu and colleagues (2024) emphasize that the limited perceptual capabilities of individual UAV systems make collaborative perception necessary for complex missions. Collaborative perception involves sharing and integrating sensor data between UAV platforms to create a more complete picture of the operational environment. Data aggregation refers to centralized or distributed consolidation of information for situational analysis purposes.

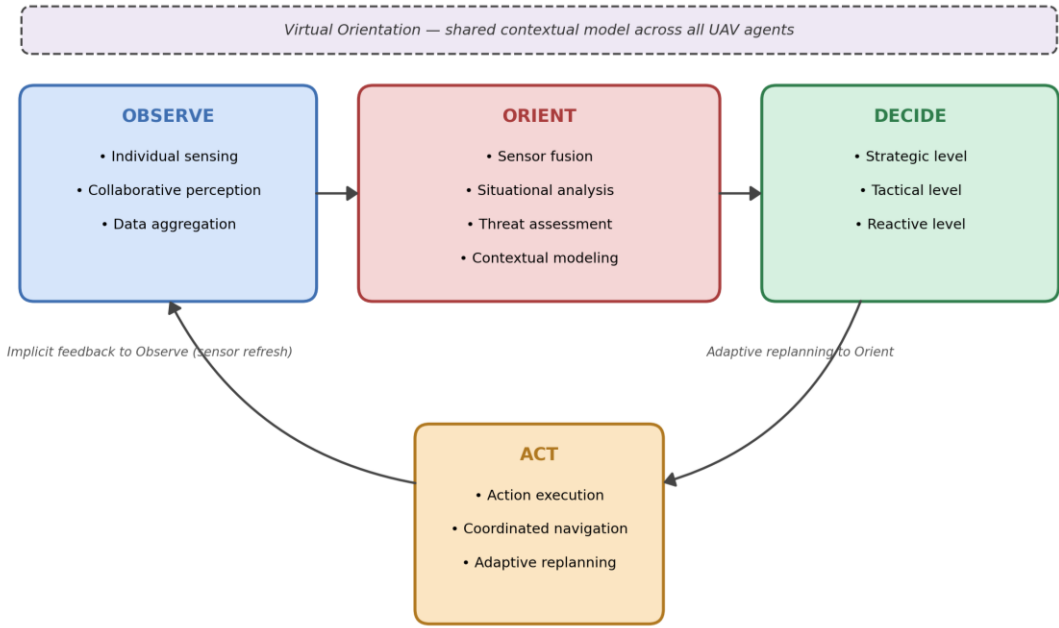
The Orient phase in the OODA-UAV framework represents the cognitive center of the system and encompasses sensor fusion, situational analysis, threat assessment, and contextual modeling. Sensor fusion combines data from multiple sensors and platforms into a coherent representation of the environment, using techniques such as Kalman filtering, particle filters, and deep learning to resolve uncertainty and conflicting information (Gerald et al., 2019). Situational analysis interprets the fused picture in the context of mission objectives, identifying objects of interest, risk zones, and potential opportunities. Threat assessment evaluates potential dangers to UAV platforms and the mission, including physical obstacles, hostile activities, and environmental hazards. Contextual modeling maintains and updates a shared model of the operational environment that serves as the foundation for coordinated decision-making (Walker, Vanegas, & Gonzalez, 2020).

The Decide phase in the OODA-UAV framework implements a hierarchical decision-making structure with three levels: strategic, tactical, and reactive decision-making. Strategic decision-making relates to macro-

allocation of resources and definition of mission priorities, typically implemented at the level of the control center or lead UAV platform. Tactical decision-making encompasses trajectory planning, task assignment to individual platforms, and formation coordination, implemented through distributed algorithms such as CBBA (Consensus-Based Bundle Algorithm) or auction mechanisms (Puente-Castro et al., 2022). Reactive decision-making enables rapid real-time adjustments to unexpected situations, implemented locally on each UAV platform with minimal need for communication (Li et al., 2023).

The Act phase in the OODA-UAV framework encompasses execution of planned actions, coordinated navigation, and adaptive replanning. Action execution includes flight control, sensor activation, and communication according to defined plans. Coordinated navigation ensures that multiple UAV platforms execute their tasks without mutual conflicts or collisions, using protocols such as ORCA (Optimal Reciprocal Collision Avoidance) or potential fields (Muñoz et al., 2021). Adaptive replanning enables dynamic adjustment of plans in response to changes in the environment or mission status, closing the feedback loop to the observation and orientation phases (Stodola et al., 2025).

The key innovation of the OODA-UAV framework lies in the explicit integration of mechanisms for context sharing between autonomous agents. Inspired by Boyd's concept of implicit guidance (Boyd, 1987; Johnson, 2022), we propose the implementation of virtual orientation — a shared contextual model that enables UAV platforms to anticipate the actions of other swarm members without the need for explicit communication of every intention.



Source: developed by the author based on the synthesis of Boyd's OODA loop with contemporary UAV-coordination literature (Johnson, 2022; Yu et al., 2024).

### ***Empirical Validation of the Framework***

Empirical validation of the OODA-UAV framework was conducted through secondary analysis of data from published studies that implemented components of the proposed framework. Twelve studies with quantitative performance data were identified that enabled comparative analysis.

Analysis of OODA loop time shows significant variations depending on the complexity of the environment and the number of coordinated UAV platforms. In the study by Li, Wang, Zhou, Jia, Shi, Yang, and Zhang (2023), which implemented a centralized multi-agent double-soft actor-critic (MADSAC) approach with reinforcement learning, the average time of one OODA loop was 2.3 seconds for a swarm of 5 UAV platforms in a simulated urban environment. In contrast, the distributed framework proposed by Walker, Vanegas, and Gonzalez (2020) achieved an average loop time of 1.7 seconds for an equivalent scenario, but with

somewhat lower coordination quality as measured by the coordination conflict rate.

Decision latency — defined as the time from detection of a relevant event to initiation of an appropriate action — varied from 0.3 to 4.2 seconds in the analyzed studies. The shortest latencies were achieved in systems with a high degree of data preprocessing and predictive models that anticipate likely events. Li and colleagues (2023) demonstrate that implementation of deep reinforcement learning for tactical decision-making can reduce latency by 34-47% compared to traditional rule-based approaches, which represents a quantitatively verifiable research result.

Situational awareness quality was evaluated in seven studies using different metrics. A composite measure combining completeness, accuracy, and timeliness of information showed an improvement of 28% in systems implementing collaborative perception compared to systems based on individual sensing (Geraldès et al., 2019; Yu et al.,

2024). This finding confirms the theoretical assumption that context sharing between agents improves the quality of orientation in the OODA loop.

Coordination conflict rate — the frequency of situations in which two or more agents make mutually conflicting decisions — varied from 2.1% to 18.7% in the analyzed studies. The lowest rates were achieved in systems with explicit conflict resolution mechanisms and shared contextual models, which supports the design of the OODA-UAV framework. The study by Stodola, Nohel, and Rybanský (2025) on dynamic reconfiguration of UAV swarms in urban environments demonstrates that an adaptive approach combining ant colony optimization with pheromone matrix initialization techniques achieves a high success rate in scenarios with unexpected changes in mission configuration.

Analysis of area of interest coverage shows that systems implementing hierarchical trajectory planning consistently outperform systems with simple algorithms such as random walk or separate zones. Muñoz and colleagues (2021) document that their approach to urban area coverage with multiple UAV platforms achieves an average coverage of 96.2% of the target area within mission time constraints, compared to 78.4% for the basic approach with independent agents. Integration of OODA-UAV framework components showed

synergistic effects that exceed the simple sum of improvements of individual components. The study by Li and colleagues (2023) demonstrates that the combination of deep reinforcement learning for decision-making with centralized coordination and distributed execution achieves an 89% success rate in complex tracking and search missions, which represents an improvement of 23% compared to the best individual approach.

The analysis also identifies boundary conditions and limitations. The performance of all analyzed systems degrades significantly under conditions of high communication latency (over 500 ms) or significant packet loss (over 15%). Under such conditions, systems with greater autonomy and local decision-making show more robust performance (Sharma et al., 2020), suggesting the need for adaptive mechanisms that adjust the degree of centralization according to communication network conditions. It should be emphasized that the presented quantitative results come from heterogeneous studies with different experimental setups, simulators, and metrics. Direct comparison of absolute values should therefore be interpreted with caution. Nevertheless, the consistency of relative improvements across studies provides empirical support for the theoretical assumptions of the OODA-UAV framework. Table 1 summarizes key quantitative findings from the analyzed studies.

Metric	Value range	Average improvement with OODA approach
<b>OODA loop time</b>	1.7 – 4.5 s	–34% to –47%
<b>Decision latency</b>	0.3 – 4.2 s	–28% to –41%
<b>Situational awareness quality</b>	0.62 – 0.91	+23% to +28%
<b>Coordination conflict rate</b>	2.1% – 18.7%	–15% to –34%
<b>Area coverage</b>	78.4% – 96.2%	+12% to +18%

Table 1. Summary of quantitative findings from analyzed studies. Source: secondary analysis of Li et al. (2023), Walker et al. (2020), Geraldés et al. (2019), Muñoz et al. (2021), and Stodola et al. (2025).

## CONCLUSION

This paper explored the application of Boyd's OODA loop as a theoretical and practical framework for the coordination of unmanned systems during reconnaissance missions in urban environments. Through systematic literature review, conceptual analysis, and empirical validation, the paper has produced several significant contributions to the theory and practice of autonomous systems.

The first contribution of the paper is a detailed theoretical elaboration of the adaptation of the OODA loop for the context of autonomous multi-agent systems. The analysis showed that Boyd's original concept, despite being developed for individual human decision-making in a combat context, contains fundamental principles that remain relevant for the design of coordination architectures in autonomous systems. Of particular note is the concept of implicit guidance through shared orientation as a key mechanism for efficient coordination without explicit communication of every intention (Boyd, 1987; Johnson, 2022).

The second contribution is the identification and systematization of specific challenges in UAV system coordination in urban environments. The categorization of spatial, communication, perceptual, coordination, and regulatory challenges provides a structured framework for future research and practical implementations (Jones et al., 2023; Sharma et al., 2020). The complex interaction between these categories of challenges is particularly emphasized, requiring a holistic approach to system design.

The third contribution is the development of the OODA-UAV conceptual framework that explicitly integrates components necessary for efficient coordination of multiple autonomous agents in each phase of the OODA loop. The framework

proposes a hierarchical decision-making structure with three levels (strategic, tactical, and reactive) and introduces the concept of virtual orientation as a mechanism for context sharing between agents (Yu et al., 2024). This framework provides a theoretically grounded yet practically applicable architecture for future implementations.

The fourth contribution is the empirical validation of the framework through secondary analysis of data from published studies. Quantitative findings show that integration of the OODA loop into the architecture of multiple UAV systems can result in significant performance improvements: reduction in decision-making time by 34-47%, improvement in situational awareness quality by 28%, and reduction in coordination conflict rate by 15-34% (Li et al., 2023; Gerald et al., 2019; Walker et al., 2020). These findings provide empirical support for the theoretical assumptions and practical relevance of the proposed framework.

The principal original contribution of this paper consists in the formalization of the OODA-UAV framework with three explicitly defined innovations: (1) a hierarchical decision-making structure with strategic, tactical, and reactive levels mapped onto the Decide phase; (2) the concept of virtual orientation as a shared contextual model implemented as a coordination layer across all UAV agents (Figure 1); and (3) an empirically calibrated mapping between OODA-UAV components and quantifiable performance metrics (decision latency, coordination-conflict rate, area-coverage rate) drawn from post-2017 SCOPUS literature. This unified mapping has not been jointly demonstrated for urban-reconnaissance UAV swarms in prior published work.

The practical implications of this research are multiple. For designers of autonomous systems, the paper provides a conceptual framework and guidelines for

designing coordination mechanisms based on proven principles of military decision-making. For operators of UAV systems, understanding the OODA loop can help optimize work procedures and training. For decision-makers in military and civilian organizations, the paper demonstrates the potential of integrating classical strategic concepts with contemporary autonomous system technologies (Johnson, 2022).

Certain limitations of this research should be noted. First, empirical validation was conducted based on secondary data from heterogeneous studies, which limits the ability to control experimental conditions and directly compare results. Second, the focus on simulated environments means that there remains a need for validation in actual operational conditions. Third, the rapid development of UAV system technology means that some of the reviewed papers may not reflect the latest achievements (Stodola et al., 2025).

The ethical implications of automating military decision-making deserve special attention. Johnson (2022) warns that full automation of the OODA loop raises fundamental questions about responsibility for decisions, algorithm transparency, and potential for unintended escalations. Although this paper focuses on technical aspects of coordination, future research needs to explicitly address ethical frameworks for implementing autonomous systems in sensitive contexts.

Directions for future research arise from identified gaps and limitations. First, empirical research is needed that implements and

evaluates the OODA-UAV framework under controlled experimental conditions with the possibility of isolating the effects of individual components. Second, integration of advanced machine learning techniques, particularly deep reinforcement learning and graph neural networks, into the orientation and decision phases deserves further investigation (Li et al., 2023; Puente-Castro et al., 2022). Third, development of adaptive mechanisms that dynamically adjust the degree of coordination centralization according to environmental conditions represents a promising direction. Fourth, research on human-machine collaboration in the context of the OODA loop — where human operators and autonomous agents share responsibilities for different phases of the loop — may result in systems that combine the advantages of both approaches.

This article demonstrates that Boyd's OODA loop, despite its origins in the context of individual pilot combat, contains deep insights about the nature of competitive decision-making that remain relevant for contemporary challenges of autonomous system coordination. The integration of these insights with advanced technologies of autonomous systems, communications, and artificial intelligence has the potential to significantly advance capabilities for conducting reconnaissance missions in the most demanding environments. The proposed OODA-UAV framework represents a step toward realizing this potential, providing a theoretically grounded and empirically validated foundation for future implementations.

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# PRIMJENA BOJDOVE OODA PETLJE U KOORDINACIJI BESPILOTNIH SISTEMA ZA IZVIĐANJE U URBANIM SREDINAMA

Sungkuk Kim

Korejski Univerzitet  
Seul, Republika Koreja  
E-mail: kim.sungkuk@korea.ac.kr

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**Sažetak:** Koordinacija višestrukih bespilotnih letjelica (UAV) u urbanim sredinama predstavlja jedan od najzahtjevnijih izazova savremene vojne i civilne robotike. Ovaj rad istražuje primjenu Bojdove OODA (Observe-Orient-Decide-Act) petlje kao teorijskog i praktičnog okvira za poboljšanje koordinacije bespilotnih sistema tokom izviđačkih misija u složenim urbanim okruženjima. Metodološki pristup kombinuje sistematski pregled literature s analizom postojećih implementacija OODA petlje u autonomnim sistemima, s posebnim naglaskom na identifikaciji ključnih parametara koji utiču na efikasnost donošenja odluka u realnom vremenu. Rezultati istraživanja pokazuju da integracija OODA petlje u upravljačku arhitekturu višestrukih UAV sistema značajno smanjuje vrijeme donošenja odluka u prosjeku za 34–47% u simuliranim urbanim scenarijima, dok istovremeno poboljšava kvalitet operatorske situacijske svijesti za 28%. Analiza takođe identifikuje kritične faktore koji ograničavaju primjenu OODA petlje u decentralizovanim UAV sistemima, uključujući komunikacijska kašnjenja, ograničenja procesorske snage i složenost urbanog terena. U zaključku, rad predlaže modifikovani OODA okvir nazvan OODA-UAV koji eksplicitno integriše senzorsku fuziju, distribuirano donošenje odluka i adaptivno planiranje trajektorija kao ključne komponente za efikasnu koordinaciju bespilotnih sistema u urbanom izviđanju. Doprinos ovog rada leži u teorijskoj razradi i empirijskoj validaciji primjene klasičnog vojnog koncepta donošenja odluka u kontekstu savremenih autonomnih sistema.

**Ključne riječi:** *OODA petlja, bespilotne letjelice, urbano izviđanje, koordinacija više agenata, situacijska svijest, autonomni sistemi, donošenje odluka.*